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Luminosity and Redshift Dependence of Quasar Spectral Properties

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Abstract. Using a large sample of quasar spectra from the SDSS, we examine the composite spectral trends of quasars as functions of both redshift and luminosity, independently of one another. Aside from the well known Baldwin effect (BE) – the decrease of line equivalent width with luminosity – the average spectral properties are remarkably similar. Host galaxy contamination and the BE are the primary causes for apparent changes in the average spectral slope of the quasars. The BE is detected for most emission lines, including the Balmer lines, but with several exceptions including NV1240A. Emission line shifts of several lines are associated with the BE. The BE is mainly a function of luminosity, but also partly a function of redshift in that line equivalent widths become stronger with redshift. Some of the complex iron features change with redshift, particularly near the small blue bump region.

1. Introduction

The Sloan Digital Sky Survey (SDSS, York et al. 2000) is now identifying tens of thosands of new quasars a year. The large sample, wide ranges of both redshift and luminosity, and the high-quality calibrated spectra, make the SDSS quasar sample extraordinarily useful for exploring the dependence of spectral properties on redshift and luminosity – two of the most important parameters for any extragalactic population. Here we present initial results on the composite spectral properties of more than 16000 quasars from the SDSS.

2. The Dataset and Composite Spectrum Construction

The quasar data are taken mainly from the SDSS First Data Release (DR1, Abazajian et al. 2003), appended with several hundred more post-DR1 quasar spectra in order to extend the redshift and luminosity coverage. Quasars in the DR1 are described by (Schneider et al. 2003). We modify the definition of quasar here to mean any extragalactic object with at least one emission line FWHM of at least 1000km/s, and impose no luminosity criteria. We also remove from

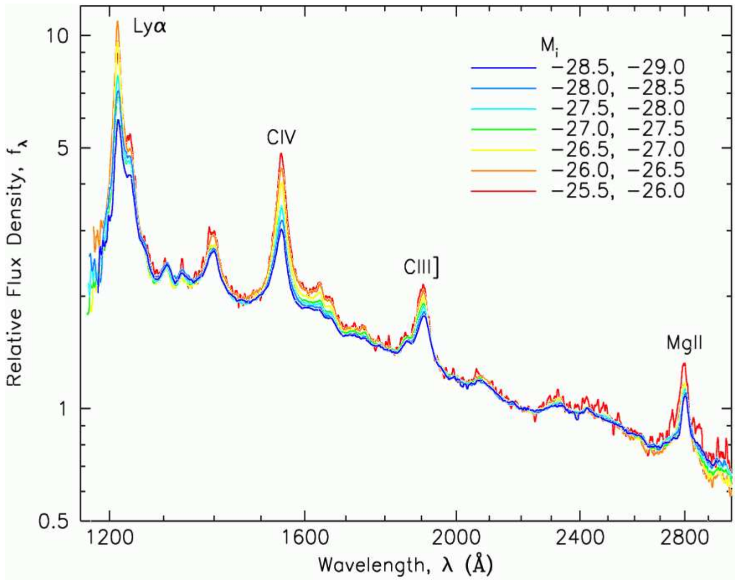

Figure 1. Composite quasar spectra from the same small range of redshift but at different luminosities. The flux densities have been normalized at 2200Å. The spectra are nearly indistinguishable except for the Baldwin effect – the decrease in emission line equivalent width with luminosity.

consideration any spectrum with an apparent broad absorpion line or strong associated absorption line, since these significantly affect the true profiles of some emission lines. Spectra with long unprocessable wavelength ranges are also rejected. The luminosity is measured as the rest frame K-corrected i band absolute magnitude, M_i, measured at the spectral epoch to avoid variability effects, using a flat cosmology with $\Omega_M = 0.3, \Omega_\Lambda = 0.7, H_0 = 70$km/s/Mpc.

The full sample consists of 16716 independent quasar spectra from the SDSS. The sample was divided into redshift bins of width $\Delta log(1 + z) = 0.04$ starting at $z = 0$, and absolute magnitude bins of half a magnitude. Composite spectra were generated for each bin by calculating the geometric mean of all of the spectra contained in the bin, using techniques similar to those described by Vanden Berk et al. (2001). The geometric mean preserves the average index of a set of power laws. We have found that the resulting composite spectra do not change greatly when at least about 20 spectra are combined. In this analysis we consider only bins with at least 20 spectra; there are 133 such bins, spanning redshifts beyond 4.7 and absolute magnitudes from -20 to -29.5.

3. Results

One of the primary conclusions of this study is that the *average* spectral properties of quasars do not vary greatly as a function of either redshift or luminosity. The primary trend with either parameter is the decrease of most emission line equivalent widths with luminosity – the well-known Baldwin effect (BE, Baldwin 1977). To illustrate this, Fig. 1 shows seven composite spectra from the same

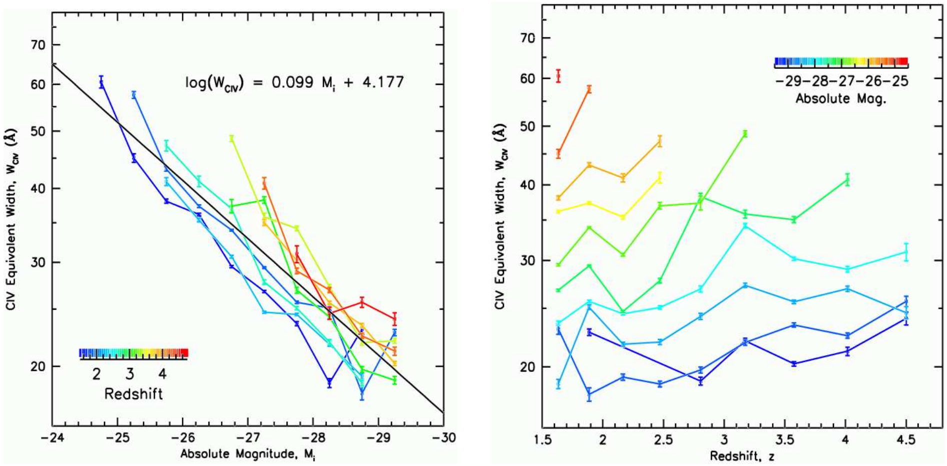

Figure 2. The CIV equivalent width as a function of both luminosity (left) and redshift (right) in small ranges of the other parameter.

redshift bin, $2.020 \leq z < 2.311$, but spanning more than an order of magnitude in luminosity. The spectra are normalized to unity at a rest wavelenth of 2200Å, and they are color coded to show the absolute magnitue bin range. The BE is obvious for most emission lines, but especially Ly α and CIV λ1549. Notable exceptions include OI, AlIII, and most likely NV.

It can be discerned from Fig. 1 that the peaks of several of the lower ionization lines, e.g. MgII λ2800, shift redward with increasing luminosity. Since these lines are expected to lie at close to the systemic redshifts of the quasars, and the measured redshifts rely more strongly on the CIV high-ionization line, in reality it is the high-ionization lines that are increasingly *blushifted* with luminosity. This confirms the relationship between line shift and the Baldwin effect found by Richards et al. (2002).

The continuum slopes of the spectra in Fig. 1 are remarkably similar. However, at redshifts below about 0.5, the slopes become bluer with luminosity. The reason for this is that host galaxy contamination increases with decreasing luminosity, making the quasar spectrum appear redder. We have confirmed this by fitting the low-z composite spectra with a pure quasar and a pure galaxy component using sets of eigenvectors. After subtracting the host galaxy component, the quasar spectra reveal a Baldwin effect for the Balmer lines and the narrow forbidden lines, a point which has previously been controversial.

While the Baldwin effect is a strong function of luminosity, Fig. 2 shows that it is also a function of redshift. The equivalent width of CIV is shown as a function of luminosity and redshift, in bins in which the other parameter is held nearly constant. The redshift dependence is weaker, but still quite significant. The redshift dependence may explain much of the “scatter” that is often found in the Baldwin effect; unfortunately this also means that the BE will remain difficult to use for cosmology since it evolves with redshift.

Finally, there are other redshift trends to note, mainly that the strengths and profiles of many of the iron complexes evolve. This occurs most notably in the so-called small blue bump region – the entire region from about 2200-4000Å

appears to become bluer with decreasing redshift. Some of this may be due to changes in the Balmer continuum, but the Fe emission complex profiles also change, indicating that Fe itself contributes at least partially to the effect.

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